

Operational Evaluation of a Weather-Avoidance Rerouting System

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The Dynamic Weather Routes system, designed to find time-saving corrections to convective weather avoidance routes for airborne flights in en route airspace, has been in operational evaluation at the American Airlines Integrated Operations Center since July 2012. This paper, following an initial study of the first three months of the evaluation, presents the potential time savings for 752 flights for which American Airlines Air Traffic Coordinators accepted weather avoidance advisories during the 2013 calendar year. These advisories are categorized by the proximity of convective weather to both the filed flight plan and the proposed route correction. While the bulk of potential savings came from aircraft receiving direct routes in clear weather, the greatest average savings per advisory (15 minutes per aircraft) resulted from route corrections around convective weather. Measurement of the time spent in analyzing advisories and resulting route corrections indicates that additional time savings can be realized by reducing communication and execution delays. Lastly, survey data validate airline confidence in the system, with an average of one advisory rejected for every seven accepted.

Nomenclature

ACARS	=	Aircraft Communication Addressing and Reporting System
ARTCC	=	Air Route Traffic Control Center
AT	=	Air Traffic
BRCC	=	Business Resumption Control Center
CIWS	=	Corridor Integrated Weather System
CWAM	=	Convective Weather Avoidance Model
DWR	=	Dynamic Weather Routes
FACET	=	Future ATM Concepts Evaluation Tool
IOC	=	Integrated Operations Center
MAP	=	Monitor Alert Parameter
NTX	=	NASA/FAA North Texas Research Station
PGUI	=	Planview Graphical User Interface
SAA	=	Special Activity Airspace
TMI	=	Traffic Management Initiatives
TMU	=	Traffic Management Unit
TRACON	=	Terminal RADAR Approach Control
VNC	=	Virtual Network Computing
ZFW	=	Fort Worth ARTCC

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I. Introduction

Weather causes delays and inefficiencies in the US National Airspace System, and the inability to anticipate the impact of wind and weather changes on filed aircraft routes can lead to in-flight delays and excessive fuel use. In particular, dispatchers and air traffic managers cannot readily assess weather and traffic conditions to identify and act on time-saving opportunities.

NASA's Dynamic Weather Routes (DWR) system continuously and automatically analyzes in-flight aircraft in en route airspace and proposes time-saving corrections to current weather avoidance routes.¹ Using trajectory automation with current and forecast weather models, DWR tries to find more efficient routes around weather while considering wind-corrected flying time, downstream sector congestion, and traffic conflicts. Following a series of simulation evaluations and live-data shadow tests, NASA began operational evaluation of DWR in July 2012 in collaboration with American Airlines at their Integrated Operations Center (IOC).

A detailed description of the DWR system and the first three months of this operational evaluation have been documented². The purpose of this paper is to examine the results of one full year (2013) of operational use of the DWR system at American Airlines, comparing data with the earlier results where possible. The first portion of the paper provides an overview of the system and the general procedure used to evaluate, accept, and modify a flight plan based on a DWR advisory. Categorization of typical DWR advisories follows. This categorization is then used to examine the potential time savings of the advisories that American Airlines accepted, and when these occurred in 2013. The next section consists of an analysis of the time spent in the review and execution of DWR advisories, and concludes with feedback from the DWR users, based on questionnaire data.

II. DWR System Description and Procedures

A. System Description

DWR is a ground-based trajectory automation system that continuously and automatically analyzes in-flight aircraft in en route airspace to find simple time- and fuel-saving improvements to current en route Center flight plans. This tool automatically identifies and proposes simple modifications to active Center flight plans to save both time and fuel. DWR considers the current and forecast weather, convective weather, wind-corrected flying time, traffic conflicts, sector congestion, Special Activity Airspace (SAA), and reroute Traffic Management Initiatives (TMI). The graphical user interface allows airline Air Traffic (AT) Coordinators and dispatchers to visually evaluate proposed routes and modify them if necessary. While the system currently undergoing evaluation and discussed in this paper is limited to airline use, the overall concept provides for automated communication between an airline DWR operator and a Federal Aviation Administration (FAA) Traffic Management Coordinator (TMC) via displays linked through a single computer. The test set-up used, however, only allowed modification and approval of the new flight plans via today's procedures. Other papers present the DWR system, its algorithms,^{1,3} and the time-saving benefits accrued in the initial operational evaluation² in more detail.

The system architecture for the operational evaluation appears in Fig. 1. DWR software components, appearing in blue boxes at the bottom of the figure, include the trajectory automation features of the Center/TRACON Automation System (CTAS) and the Future ATM Concepts Evaluation Tool (FACET), both proven air traffic management decision support tools developed by NASA. The Weather Model box in Fig. 1 represents the Convective Weather Avoidance Model (CWAM)⁴ process, updated with current and forecast wind and weather information. CWAM is a probabilistic model of pilot deviation for weather as a function of storm intensity and storm tops. The Autoresolver algorithm develops routes to avoid both air traffic and weather. CWAM display contours are based on the current convective weather, the forecast growth and movement of that

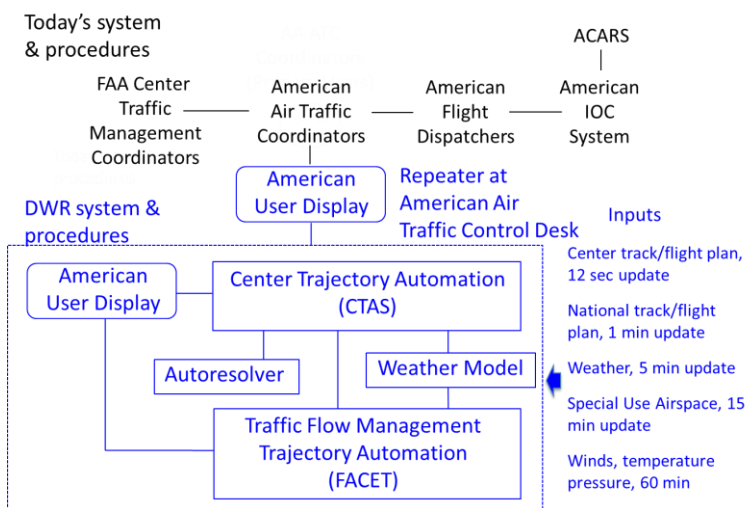


Figure 1. DWR system architecture (adapted from Ref. 2).

weather, and the percentage of pilots that would fly within a certain proximity to the convective weather. These algorithmic modules plus the American User Display process run on one server-class host machine at NASA's North Texas Research Station (NTX). An interactive repeater of the American User Display, using Virtual Network Computing (VNC) technology, is sent via a microwave link to the IOC. There, the current physical system consists of a thin-client computer, monitor, and printer located at an American Airlines AT Coordinator desk. The printer, in addition for the field evaluation, allows printing of screen captures of an advisory for dispatcher reference. The portion of the diagram in black is unaltered from today's operations; DWR does not interrupt or replace the American Airlines' method of communicating changes in flight plans to aircraft, it supplements the information that AT Coordinators and dispatchers currently use to develop flight plan modifications.

B. Display

As shown in Fig. 2, five main windows on one screen make up the standard DWR display. White text labels used here describe important features, but do not appear on the display itself. The DWR windows include (clockwise from upper left in Fig. 2): (1) the DWR Planview Graphical User Interface (PGUI) window, (2) the Active Flight Plan window, (3) the Trial Flight Plan window, (4) the Sector Map window, and (5) the Trial Planner window. The PGUI and Trial Planner windows state in the upper left of the window that they are showing the AAL Dispatch Display. Additional dialog boxes also appear, as required by the execution of various commands. This section provides a brief overview of the features of this display relevant to this paper; a more complete description of DWR display functionality appears in a previous work².

The PGUI window (1) lets the DWR user see any weather cells or traffic conflicts in the context of the air traffic being controlled by ZFW Center. The user can visually compare a trial route plan to the currently active route, interactively

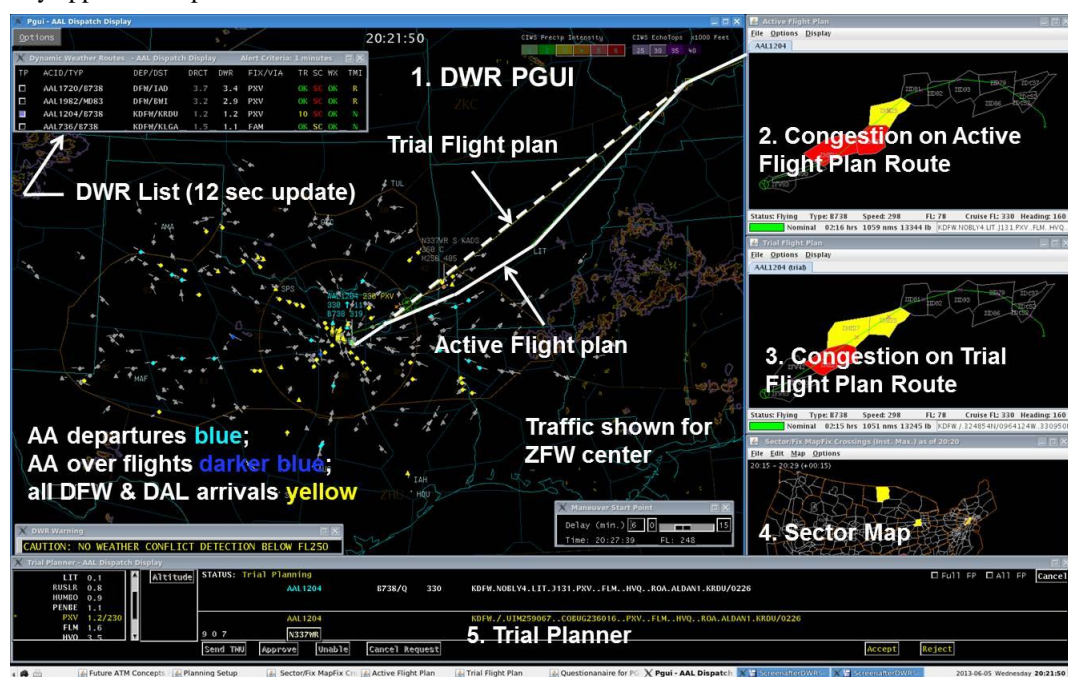


Figure 2. Overview of the DWR display.

modify trial route plans, get up-to-date weather and wind conditions as well as forecasts, and see any potential conflicts in traffic, SAA and reroute TMI. The DWR list in the upper left portion of the window shows aircraft for which the system has currently generated a proposed route correction that would save time equal to or greater than the DWR Alert Criteria. This threshold is normally set to five minutes. A supplemental audio alert notifies the AT Coordinator when a flight first appears in this list. The Coordinator can select an aircraft from this list to examine, and then evaluate the system-proposed DWR advisory. At any time, the AT Coordinator can also click on the data block of an American Airlines aircraft to manually start a trial plan for that aircraft. In this case the DWR system would display any time lost or saved of the manually altered trial plan relative to the currently filed flight plan. CIWS, using vertically integrated liquid data and echo top data and updated every five minutes, drives storm cells on the PGUI. CWAM polygons appear as dashed blue lines when a flight plan or trial plan passes within 25 miles of it, and as orange polygons when in conflict with a flight plan or trial plan.

The Active Flight Plan Congestion window (2) is a FACET window that shows the current flight path as green straight-line segments across sectors through which the flight is currently routed. If the projected traffic in the sector

at the time that the flight will travel through it exceeds that sector's Monitor Alert Parameter (MAP) value, the sector will appear as yellow or red. Yellow indicates that the projection includes flights that are not yet airborne, while red indicates that all of the flights in the projection are currently airborne. In the figure, two sectors along the active flight plan are red, and one is yellow.

The Trial Flight Plan Congestion window (3) is another FACET window. It shows the suggested DWR flight path as green straight-line segments across the sectors through which the flight would be routed. Again, if a sector is projected to have heavy traffic during the time that the flight will travel through that sector, the sector will appear as yellow or red. The Trial Flight Plan Congestion window also shows any active reroute TMI or SAAs that could affect the proposed route. In Fig. 2, this window indicates an improvement in sector congestion compared with the Active Flight Plan window, as it moves the flight from a red sector to a yellow sector.

The Sector Map window (4) is a FACET window that shows a map of all the sectors in the contiguous 48 states. This window is displayed along the right hand side of the screen, just below the Trial Flight Plan window. It shows all currently heavily-loaded sectors at all times, regardless of whether or not a DWR advisory is in the Trial Planner.

The Trial Planner window (5) occupies the full width at the bottom of the screen. This window displays the current and proposed DWR flight plans of the aircraft undergoing trial planning. The flying time difference between the current and proposed flight plans, that is, the time savings, appears on a fix-by-fix basis in the left portion of the window. Positive values indicate a time savings, while negative values indicate time lost. On the lower right of the window are two buttons, labelled "Accept" and "Reject," which the AT Coordinator uses to either accept the trial plan as portrayed on the display, or reject it. Either of these choices will initiate a questionnaire that allows the AT Coordinator to provide feedback on the selection. The trial plan remains in the window after Acceptance or Rejection, updated to reflect flight progress and any flight plan amendments. A "Cancel" button on the upper left corner of this window clears the trial plan window without the AT Coordinator having to Accept or Reject the current trial plan, and also empties the window of data following a flight plan Acceptance or Rejection.

C. General Procedure

Figure 3 shows the typical sequence of events for a DWR advisory to become a flight plan amendment. American Airlines and NASA worked together to develop this sequence for using the DWR system in harmony with IOC roles and procedures.

First, a DWR advisory that met the Alert Criteria appeared on the DWR list. As shown in the right column of Fig. 3, this moment was denoted as the "Advisory" time for this particular proposal. When ready, the AT Coordinator selected this aircraft from the list, starting the trial plan. The AT Coordinator examined the route, modified it if needed, and could "Accept" or "Reject" the displayed trial plan. These choices caused a questionnaire to appear on the screen (as described later in the paper). If the AT Coordinator thought that the crew should act on the proposed advisory, the AT Coordinator usually forwarded the proposed flight plan amendment to the flight's dispatcher by either printing a screen capture of the display (showing the current and trial plan routes), or manually writing the proposed flight plan amendment. The AT Coordinator then called the dispatcher with the information, or walked it to the dispatcher's position. The dispatcher analyzed the proposed amendment and determined if the crew should ask air traffic control for the flight plan correction. If so, the dispatcher sent this proposed route modification to the crew via the Aircraft Communication Addressing and Reporting System (ACARS).

The crew chose whether or not to pursue the flight plan change after receiving the ACARS message, and would verbally request the DWR route modification from its current air traffic controller. Using today's normal procedures, the controller assessed the impact of making the flight plan amendment, arranged coordination with other sectors and/or the Traffic Management Unit (TMU) if needed, and amended the flight plan if the new route was approved.

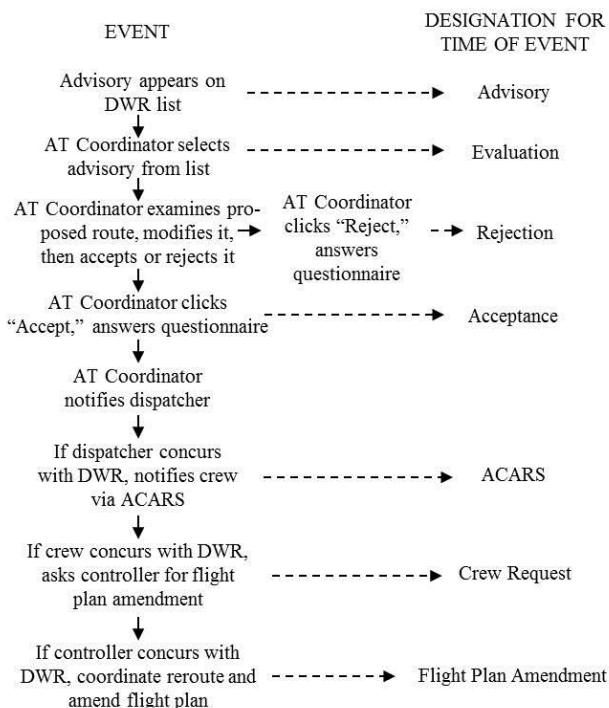


Figure 3. Typical DWR event timeline.

III. Scope of Test and Data Collection

American Airlines began using the DWR system in its IOC in July of 2012. Following an initial period of training, AT Coordinators began accepting and rejecting proposed advisories, primarily for NASA to gain an understanding of the kind of direct routes American Airlines would like to accept, but always with the option for TMCs and dispatchers to act on the recommended route corrections.

The evaluation period for 2013 started with American's air traffic coordination and dispatcher operations temporarily relocated from its IOC to its Business Resumption Control Center (BRCC) because of renovations to the former location. The BRCC is a smaller facility than the IOC, and the DWR display was located immediately behind the AT Coordinator position, giving the AT Coordinator easy access. During this time the DWR Alert Criteria was set to three minutes. This allowed AT Coordinators more opportunities to use the system while they trained.

American Airlines resumed dispatch operations in the IOC on April 9, 2013. The new IOC location for DWR was at the diversion desk, making it was readily available when that position was opened for weather events, but less convenient for the AT Coordinator to use in clear-weather operations as it was behind and one desk to the side of the AT Coordinator position. A final operational change involved increasing the DWR Alert Criteria from three to five minutes on April 22. This was to reduce the number of DWR alerts for relatively small time savings, as the number of large-time-saving advisories was expected to rise with the increase of convective weather activity in the spring.

DWR route correction situations are, by definition, dependent on unpredictable weather and traffic volume, making it necessary for the research team to adopt a target-of-opportunity mentality towards data collection. Since data collection "runs" could not be scheduled in advance, the team could not count on having research observers on position to collect data. Likewise, it was impractical to have a small, dedicated cadre of subject matter experts to work with the research team as was done in past NASA operational evaluations.

Consequently, the DWR research team developed an agile and opportunistic data collection system to partially compensate for the target-of-opportunity evaluation challenges. The DWR system is, of course, fully instrumented. Every input, output, and a wide array of internal parameters are recorded and archived. Additional instrumentation is provided by the VNC-based user interface distribution system, which enables research observers to remotely monitor and analyze user interactions with DWR. This "video replay" capability has proven to be immensely valuable for filling gaps when an observer was unable to monitor the event live and for following up on user feedback. Additionally, VNC playback of DWR display activity revealed other AT Coordinator actions, such as mouse movement, printing screen captures, and showing exactly the display's appearance at the IOC. Post-test tools examined Accepted DWR advisories and flight plan amendments to estimate time savings. Lastly, NTX collected a small sample of the ACARS messages sent from dispatchers to the flight crews that indicated if and when the airline acted on a DWR advisory. In some cases, these indications were further confirmed via post-flight review of ZFW Center audio recordings, establishing if and when the crew asked for a DWR-initiated flight plan amendment and if an air traffic controller accommodated the request.

IV. Test Conditions and Analysis

The following sections present data from the past year of DWR system use at American Airlines. The first section discusses categorization of "Accepted" advisories based on weather conditions near the proposed route correction. This helps frame the conditions of the evaluation for the rest of the paper. The three sections that follow present results of a city-pair and route analysis to show the most common advisories that the AT Coordinators accepted, an analysis of the time spent on actions that resulted in a real flight plan amendment from a DWR advisory, and data from the questionnaires answered by the AT Coordinators. Note that 794 "Accepts" were recorded during this operational evaluation, but 42 of these resulted when the AT Coordinator clicked "Accept" more than once for the same advisory. The first "Accepts," totaling 752, are used for the analyses in the first three sections. Every "Accept," however, initiated a questionnaire, and all these answers are tabulated in the last section.

A. Categorization of Accepted DWR Advisories by Weather Condition

As mentioned previously, the DWR software continuously examines current flight plans and tracks of aircraft to find time-saving route corrections, even when weather is not affecting airline operations. To understand the circumstances under which American Airlines was finding acceptable DWR advisories, all of the "Accepted" cases were categorized based on the presence of weather and the kind of proposed route correction.

Two weather-related criteria were used. First, was the proposed route correction actively avoiding a weather cell? The term “actively avoiding” was defined as an advised route which was close enough to a weather cell such that the insertion of an auxiliary waypoint was required to avoid a CWAM contour. Advised routes which flew over lower altitude

weather cells which were avoided by the original route are also labeled as actively avoiding weather for this categorization.

The second criterion was, did the original filed flight plan appear to be routed to avoid a weather system that has since moved from that area? These cases typically consisted of a standard weather-avoidance route given to multiple flights. Because the route was static, however, each subsequent flight would be flying an unnecessary distance compared to the previous flight as the weather system moved away from the filed route.

The designations of the advisories and how they relate to these criteria appear in Table 1. DWR-recommended route modifications that actively avoided weather cells and were not a result of a stale weather avoidance route were designated “Classic DWRs”. Figure 4 shows a Classic DWR route correction that is suggesting an aircraft travel through a gap in a weather system instead of flying around the line of storms.

The next category covers the instance where the two criteria questions for a particular advisory were both answered with a “Yes.” In this case, as weather cells moved, fixed weather avoidance routes behind the system became more conservative in the buffer they provided between an aircraft route and the weather. Flight plan changes which proposed to route the aircraft near the convective weather on the leeward, or backside, are called “Backside DWRs”. These routes increase the savings by maintaining only the minimum required distance between the aircraft route and the weather system behind the path of the storms. An example of this suggested route correction appears in Fig. 5.

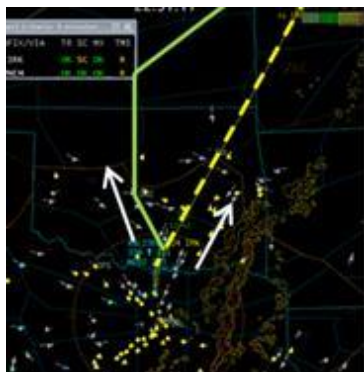


Figure 6. The Stale Weather Avoidance DWR. The green original route avoids the past weather cell location. The yellow advisory provides a direct route.

Table 1. Criteria for categorization of DWR advisories.

Question 1: Was the proposed route correction actively avoiding a weather cell?		
Question 2: Did the original filed flight plan appear to be routed to avoid a weather system that has since moved from that area?		
Answer to Question 1	Answer to Question 2	DWR Advisory
Yes	No	Classic
Yes	Yes	Backside
No	Yes	Stale Weather
No	No	Direct Route

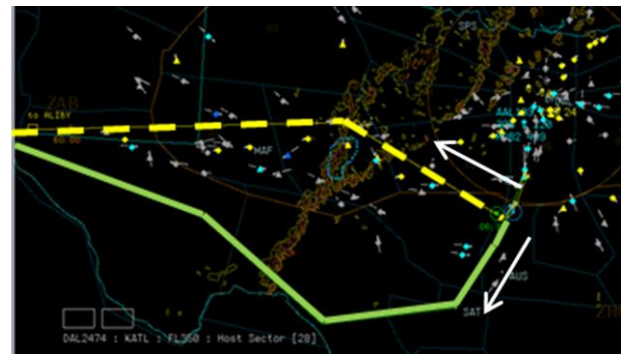


Figure 4. The Classic DWR. The green original route avoids the weather cell by flying south. The yellow advisory sends the aircraft through a gap in a weather system instead of flying around the line of storms.



Figure 5. The Backside DWR. The green original route avoids weather cells but leaves excessive space between the aircraft and weather. The yellow advisory sends the aircraft behind the storms.

The “Stale Weather Avoidance” DWR, shown in Fig. 6, results from an aging static weather-avoidance route. As weather systems moved through the area, static weather avoidance routes were filed for multiple flights. The first flights on the avoidance route flew the closest to the modeled weather, but as time progressed the route became less relevant as the distance from the route to the CIWS and CWAM boundaries increased. Most advised corrections in this situation were direct routes which removed the unnecessary “dogleg” in the filed route. Stale Weather Avoidance DWRs differed from Backside DWRs in that they were in response to an older weather avoidance route, but the route correction was well clear of the weather and typically did not include an auxiliary waypoint.

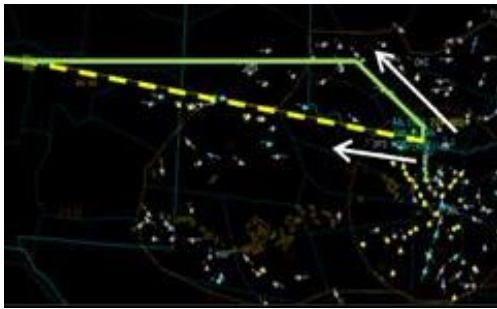


Figure 7. The Direct Route DWR. The yellow route saves time compared to the original green route.

Lastly, if both answers to the two criteria questions were “No,” convective weather played a role in neither the route of the original flight plan nor the advised route correction. These were basic “Direct Route” DWRs, as shown in Figure 7. With no convective weather directly influencing flight plan routings, the tool often found direct route short cuts that met the time savings criteria for alerting due to daily variations in wind direction and magnitude, combined with the geometric design of normal departure routes. For example, wind conditions on one day might trigger a Direct Route DWR such as that shown in Fig. 7, while on another day the same direct route would not meet the 5 minute savings criteria for a DWR alert. Additionally, the user’s ability to adjust the alerting criteria to values lower than 5 minutes will trigger more alerts for Direct Route DWRs.

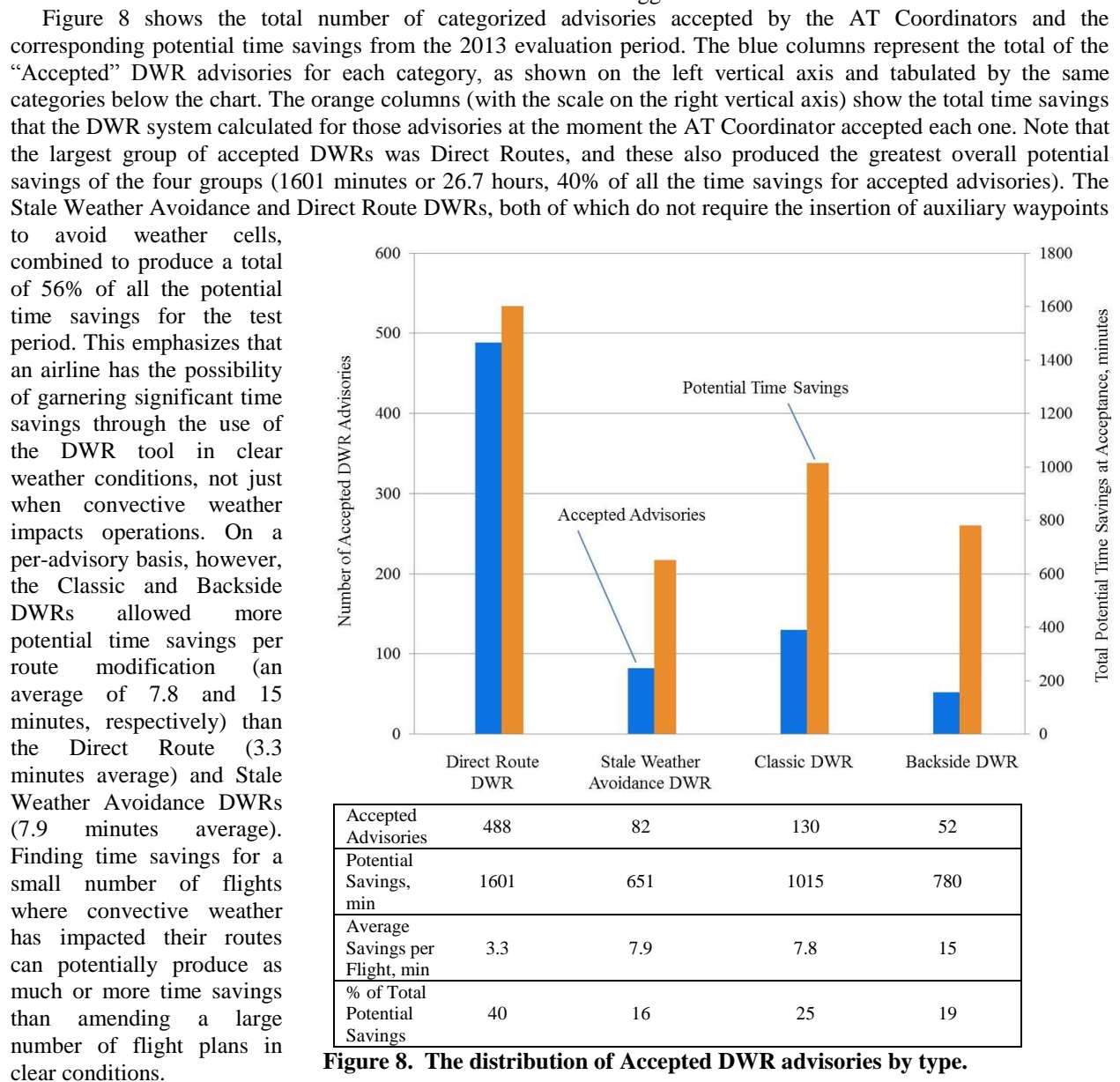


Figure 8. The distribution of Accepted DWR advisories by type.

Figure 9 shows the potential time savings data for accepted advisories, color-coded by DWR category and arranged chronologically. Blue dots represent Direct Route DWRs, orange squares show Stale Weather Avoidance

DWRs, green triangles show Classic DWRs, and black diamonds show Backside DWRs. The relocation of dispatch operations from the BRCC to the IOC appears on the figure as a vertical line (April 9), as does the change in the DWR alert criteria from three minutes to five minutes (April 22). A new DWR software build released at the end of June 2013 allowed the AT Controller to adjust the DWR alert criteria to any desired time. Note that the bulk of the accepted Direct Route DWRs occurred prior to May, and before the change in the DWR Alert Criteria from three to five minutes. American started with the three- minute criteria to generate DWRs for training purposes, and increased this to five minutes upon completion of the training and before the start of the spring convection season. Stretches of time that lack accepted route corrections show times when TM Coordinators did not respond to advisories. Note that DWR advisories involving convective weather occurred in the mid-May to mid-June time period, with additional occurrences in midsummer and early autumn. These advisories were for a wider range of savings, and usually greater potential savings per amendment, as denoted in the vertical scatter of the data points. Note that the orange, green, and black symbols tend to fall on or near each other, further denoting advisories involving weather, and that blue dots are absent from these same clusters.

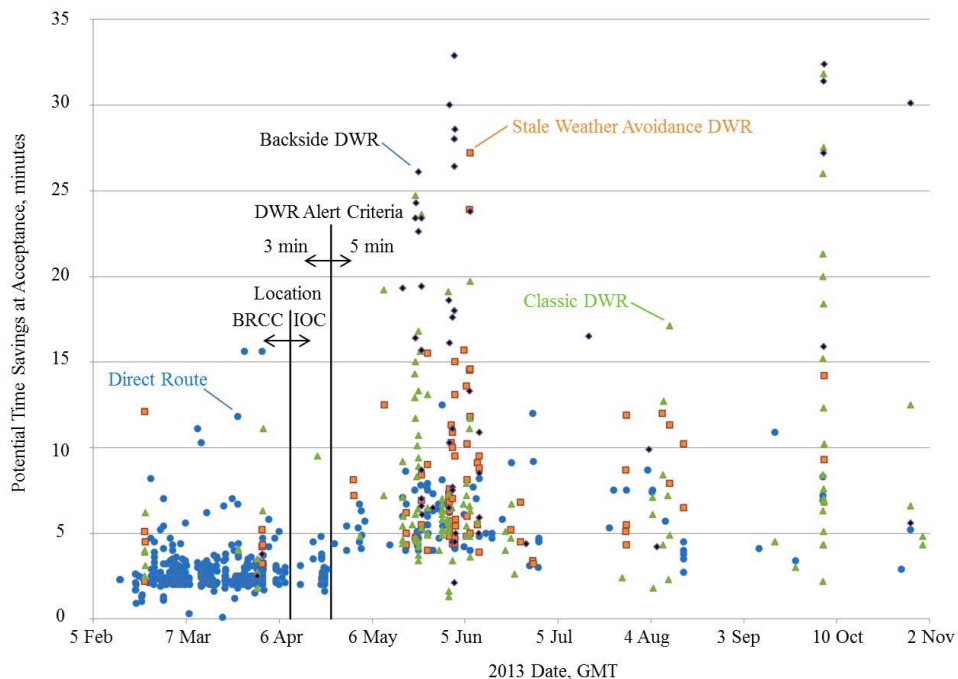


Figure 9. Chronological distribution of Accepted DWR advisories.

B. Correlation with Origin and Destination

To identify possible patterns in routes for which American Airlines was finding acceptable DWR advisories, the “Accepted” cases were categorized based on origination/destination cities. First, at a top-level, they were sorted by whether they were DFW departures or ZFW overflights. This analysis showed that 94% of the accepted advisories during the test period were for DFW departures, while only 6% were for overflights.

Accepted DWR advisories were further sorted by specific origin/destination city-pair and totals summed, to see if certain city pairs appeared more frequently than others. Figure 10 shows that a third of all accepted advisories during the 2013 testing were for DFW departures to five destination cities. The flight plans for aircraft headed to two of these cities, Miami and Fort Lauderdale, shared the same fixes in ZFW airspace.

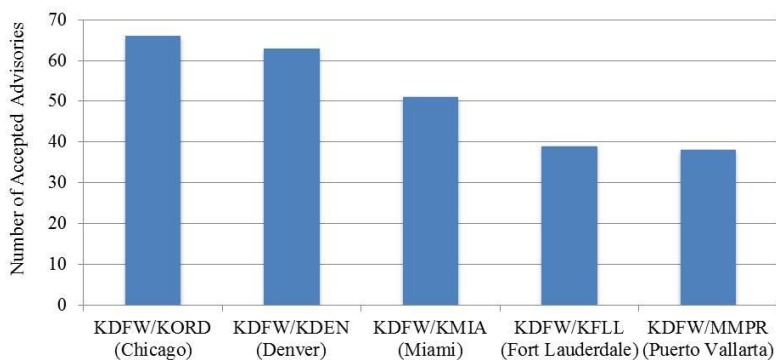


Figure 10. City-pair allocation for top third of Accepted advisories.

The DFW departure data were then further categorized by the kind of advisories that the AT Coordinator accepted, as defined in the previous section. Figure 11 contains these data for the most frequently recurring 15 destination airports seen in the 2013 test data. These destinations accounted for 415 of the 752 Accepted advisories, or 55%. On these routes, approximately 75% of the accepted advisories were Direct Routes, another 10% were Stale Weather Avoidance DWRs, and the remaining 15% were Classic and Backside DWRs. The number of accepted DWR advisories for each destination appears next to the name of the destination city. The area of each pie chart is proportional to that number, and the individual charts indicate the breakdown of accepted advisories by type. Note that departures from DFW to Chicago, an American Airlines hub, had the greatest number of accepted DWR advisories, as well as a variety of all the advisory types. While the numbers for Kansas City are relatively small, the advisories were primarily those that involved weather rather than Direct Routes.

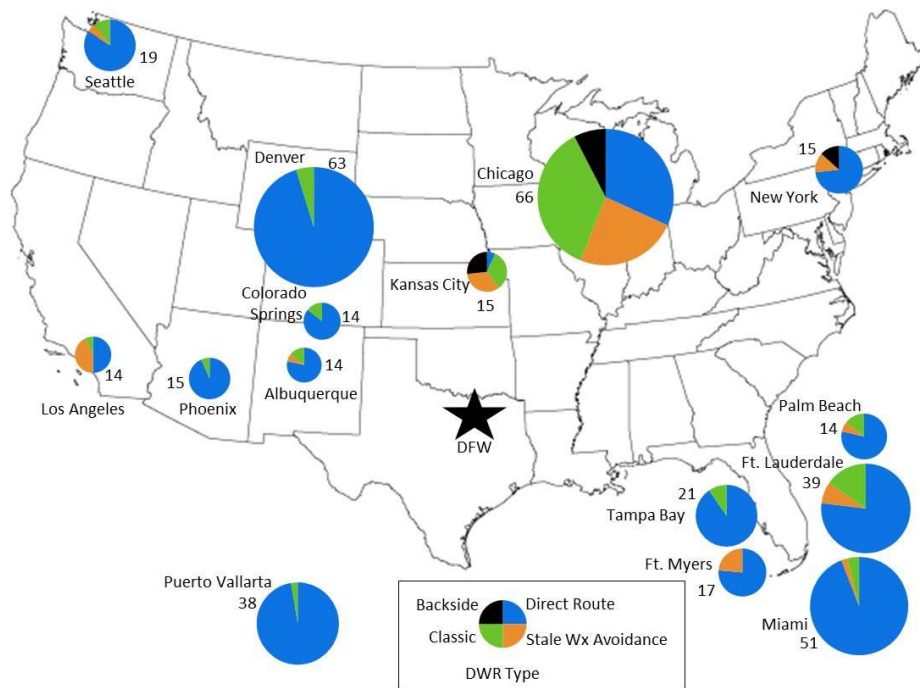


Figure 11. Breakdown of frequently recurring Accepted advisories for DFW Departures.

Accepted advisories for aircraft headed to Puerto Vallarta, Denver, and Florida destinations, however, are predominantly Direct Route DWR advisories. This difference in the mix of accepted advisories can be partly attributed to the orientation and movement of weather fronts through the Dallas-Fort Worth area, and the Midwest in general. Most lines of storms extend from north to south or northeast to southwest, and move from west to east in this region. For flights leaving DFW, this creates opportunities for the DWR system to recommend route corrections through some storms, but especially behind these fronts as they move eastward. The delay between the filing of airline flight plans and the actual departure of the aircraft also means that Backside DWR advisories become available for north-bound flights, as reflected in the breakdowns for Chicago and Kansas City.

While the frequent occurrence of certain city pairs in the data reflect the demand in American Airlines' schedules, it also reflects a limitation in this phase of the DWR system operational evaluation, in that the testing was limited to the DFW departures and overflights of just one airline and just one Center. Consequently, this grouping of the data again shows that the bulk of accepted DWR advisories for 2013 were for corrected routes not in close proximity to weather. As many flights to these city-pairs used the same daily

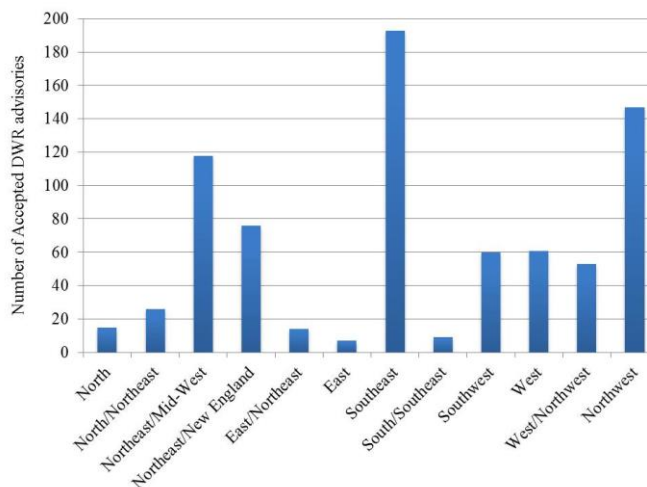


Figure 12. Distribution of Accepted DWR advisories by destination direction.

routes, the opportunities for DWR time savings were primarily determined by route geometry, airspace constraints, and variations in wind direction and magnitude that altered the savings on a day-to-day basis. The ability of an air traffic controller to grant these Direct Routes will depend on the tactical situation and airspace rules.

Revisiting all of the “Accepted” DWR advisories for DFW departures, Fig. 12 shows the distribution of the data with respect to the general direction of the original flight plans for these aircraft. Note that the bulk of the accepted DWRs were for aircraft ultimately headed to the northwest, northeast, and southeast. DFW TRACON may be pictured as a square, centered on DFW Airport with sides approximately 60 miles long and aligned with the cardinal directions. Arrival traffic flows into the TRACON via the clipped corners of this square. Departure traffic flows out the north, south, east, and west sides of the square climbing into the “departure” sectors in ZFW airspace at 18000 feet. The ZFW sectors to the northeast, northwest, southwest, and southeast of DFW TRACON serve as “arrival” sectors. Accordingly, DWR infrequently finds clear-weather time savings for DFW departures headed in the cardinal directions, but often recommends Direct Routes for aircraft which ultimately head to the northwest, northeast, and southeast. Filed departure flight plans generally avoid routes that cross the “arrival” sectors, until the aircraft reach flight level 240. The DWR tool will recommend these Direct Routes across these sectors, showing any potential tactical conflicts, and controllers will sometimes allow these flight plan changes if the airspace is conflict free and the aircraft has sufficient altitude. Thus, the geometry of the airspace greatly impacted the accepted Direct Routes.

C. Elapsed time while using the DWR system

As soon as a DWR advisory appears in the list on the display, the time benefit gained by flying the recommended route begins changing, usually decaying, as the aircraft proceeds on its filed flight plan. Therefore, the time elapsed from the appearance of an aircraft on the list to the execution of an amended flight plan needs to be minimized to gain the most time savings from DWR advisories. The 2013 operational evaluation provides insight into how much time this process takes in the real-world environment, for this particular application of the DWR tool.

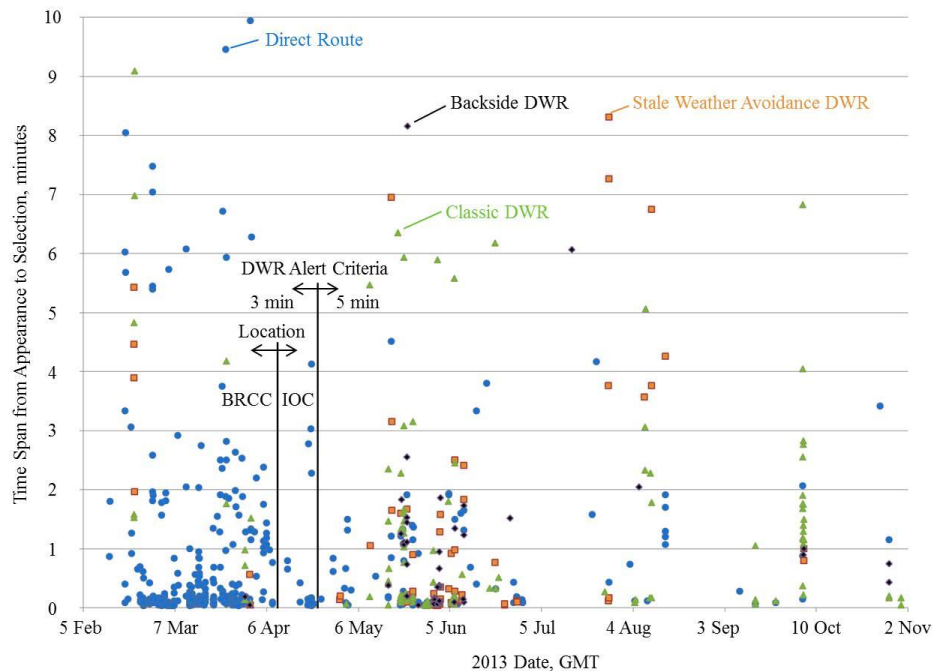


Figure 13. Reaction time to the appearance of an advisory on the DWR list.

Referring back to Fig. 3, the timeline of DWR events, the first two events are the appearance of an advisory on the DWR list, and the AT Coordinator’s selection of that advisory. Figure 13 illustrates, over the course of the year, the time that passed between each “Advisory” and “Evaluation,” that is, the time an AT Coordinator spent to respond to a DWR alert, for the Accepted DWR advisories during 2013. While 623 points (83%) show a response time of two minutes or less, some responses (74, or 10%) were in excess of five minutes. This could mean that the AT Coordinator was busy with other duties at the time the advisory appeared on the screen. Notice that the change in location (from the BRCC to the IOC) did not cause a significant change in response time, despite the fact that the DWR display location in the BRCC was closer to the AT Coordinators, versus a few steps away at the IOC. As expected, changing the Alert Criteria had no impact on the response time. Note that the response times for DWR alerts occurring in convective weather situations, while still exhibiting scatter, are generally low compared to the clear-weather days, reflecting instances when an AT Coordinator actively staffed the DWR display. The vertical “stack” of points on some of these days (especially mid-May to early June, and early October) show cases where more than one advisory appeared on the DWR list. As the AT Coordinator can only examine and “Accept” one

advisory at a time, the advisories on the list await trial planning until the one in active trial planning is Accepted, Rejected, or Cancelled. In 30 cases during this operational evaluation (approximately 3% of the total accepted and rejected advisories), the advisory which appeared first was selected after a later-arriving one; on average, the first advisory remained unselected one minute and 57 seconds longer in these cases. In summary, circumstances at the IOC influenced the response of the AT Coordinator to each alert, and led to no clear trend in response time.

Figure 14 presents, in percentile form, the elapsed time between the next two events in the DWR timeline, from “Evaluation” to either “Acceptance” or “Rejection” of the advisory. The “Accepted” DWR advisories are categorized as mentioned previously, while the “Rejected” DWR advisories have been segregated into their own category. Each line indicates the percentage of the advisories in each category accepted or rejected by the elapsed time shown on the horizontal axis.

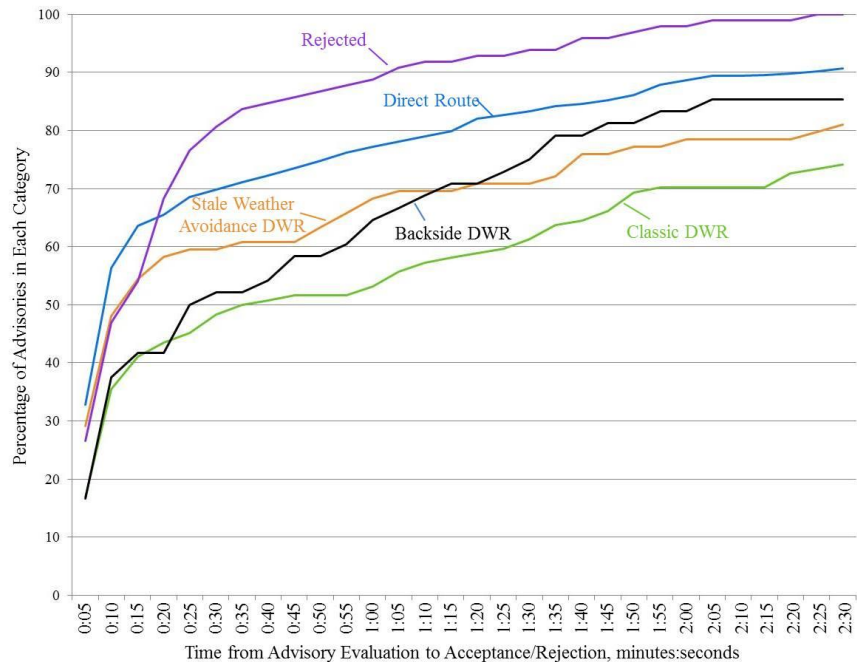


Figure 14. Time spent before Accepting or Rejecting DWR advisories.

Table 2. Events for flight plan amendments that resulted from DWR advisories.

Case	DWR	Elapsed Time, minutes:seconds				
		Evaluation to Acceptance	Acceptance to ACARS	ACARS to Crew Request	Crew Request to Flight Plan Amendment	From Evaluation to Flight Plan Amendment
A	Dir Rte	5:41	-	-	-	11:41
B	Dir Rte	2:01	-	-	-	6:15
C	Dir Rte	0:23	3:40	-	-	5:26
D	Dir Rte	0:58	-	-	-	8:50
E	Dir Rte	1:53	-	-	-	13:11
F	Dir Rte	4:10	10:00	1:06	0:26	15:42
G	Dir Rte	0:09	-	-	1:00	11:47
H	Dir Rte	1:18	-	-	5:56	12:37
I	Dir Rte	3:25	-	-	0:20	7:29
J	Dir Rte	1:09	5:23	-	-	12:14
K	Backside	1:32	9:45	-	-	18:17
L	Backside	0:06	3:06	-	-	7:26
M	Backside	2:03	3:53	5:40	1:28	13:04
N	Backside	0:45	14:02	-	-	16:00
O	Dir Rte	-	-	-	-	10:02
P	Dir Rte	-	-	-	-	5:03
Q	Dir Rte	-	-	-	-	12:12
Minimum		0:06	3:06	1:06	0:20	5:03
Maximum		5:41	14:02	5:40	5:56	18:17
Average		1:49	7:07	3:23	1:50	11:01

Average Time from Evaluation to Flight Plan Amendment, Direct Route: 10 minutes 11 seconds

Average Time from Evaluation to Flight Plan Amendment, Backside: 13 minutes 42 seconds

70% of the advisories Accepted in one minute 20 seconds or less. Equal percentages of Backside and Classic DWRs were accepted in five seconds or less (18%), with the two curves showing similar values until reaching the 50th percentile for Accepted Backside DWRs (25 seconds).

Determining how much time typically elapses for the other portions of the DWR event timeline is problematic because the DWR system cannot directly record the necessary data. ACARS messages between dispatcher and flight crew can provide some insights into DWR event timing. The American Airlines ACARS message archive was not available for this analysis; a sample of DWR-related ACARS messages, however, was collected via a research system at the NTX Research Station. Gaps exist in this data and the single antenna installation of the research system limits ACARS message reception to transmissions within line-of-sight of the NTX facility. Twenty-two of these ACARS messages match attempts to receive a flight plan amendment that DWR advised, and seven of those were recommendations to the crew to ask for the route correction. ZFW recordings of radio exchanges between aircrew and air traffic controllers supplemented the ACARS data sample. However, data available for analysis from this source is limited by the fact that recordings are only retained for fifteen days and could not be directly accessed by NASA researchers. Table 2 presents a summary of these verifications that an aircraft received a flight plan amendment based on actions resulting from a DWR advisory. Also presented for these cases is the time span from Evaluation to Flight Plan Amendment. Note that the smallest elapsed time from Evaluation to Flight Plan Amendment is 5 minutes 3 seconds (Case P). The average elapsed time from flight plan evaluation to flight plan amendment for Direct Route DWRs was three minutes and a half minutes faster than that for the Backside DWRs, but the variations in the timing of the events and the small amount of data does not provide a clear reason for this difference. For Case H, the relatively long time for the air traffic controller to grant the flight plan amendment resulted because the aircraft needed to gain altitude and executed an interim heading change for traffic avoidance.

Hypothetically, a “realistic” minimum time from Evaluation to Flight Plan Amendment could be determined using the information in Table 2. The shortest “Evaluation to Acceptance” time and “Acceptance to ACARS” time segments (0:06 and 3:06, respectively) appear in Case L. The shortest combination of “ACARS to Crew Request” (Case F) and “Crew Request to Flight Plan Amendment” (Case I) totals 1 minute 26 seconds. A rough estimate, then, of a “best combination” time for the “Evaluation to Flight Plan Amendment” category would be the sum of these values, or 4 minutes 38 seconds.

This minimum time from Evaluation to Flight Plan Amendment can be useful when looking at a broader set of Accepted DWR data. The histogram in Fig. 15 shows the distribution of flight plan amendments that may have resulted from “Accepted” advisories, ordered by the time that elapsed from “Evaluation” to “Amendment”. The distribution is plotted as a histogram with the number of amendments grouped into 1-second bins. Note that some of these flight plan amendments, a larger set than that represented in Table 2, may not be attributable to DWR advisories; the method used here is based on whether or not the aircraft received a flight plan amendment following DWR Acceptance, and if this amendment resembled the advised route

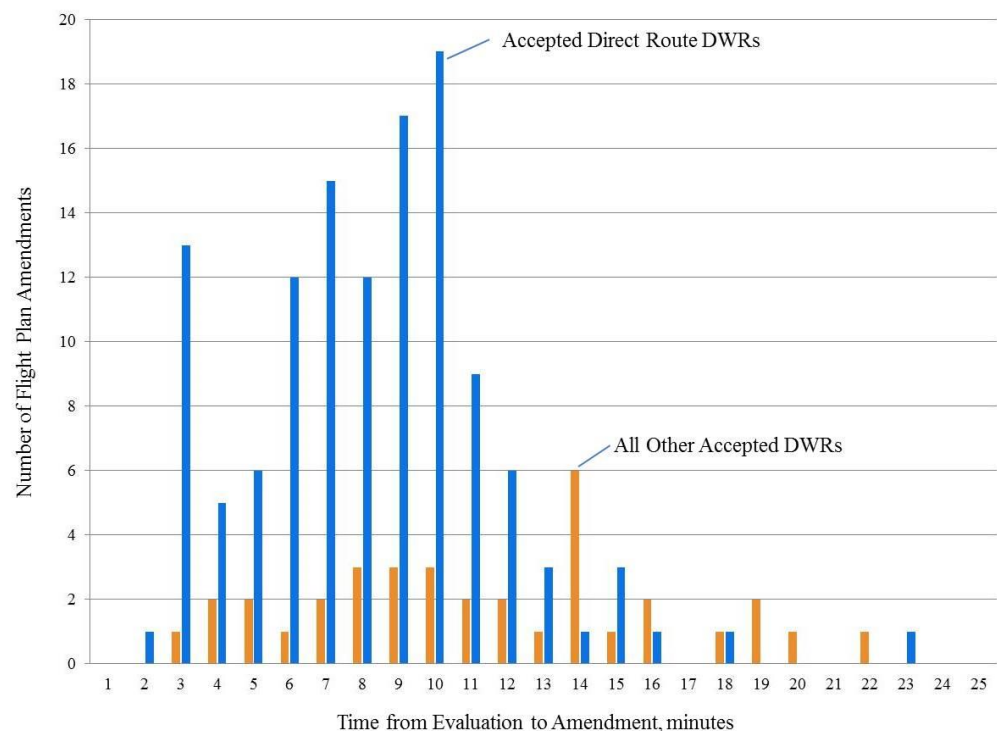


Figure 15. Elapsed time from advisory Evaluation to Flight Plan Amendment.

correction². The fact that an amendment occurred after a DWR was Accepted is not verification that dispatcher, pilot, and air traffic controller agreed that the flight plan would be amended due to the use of a DWR advisory. For route corrections that involved convective weather, a peak of six amendments occurred 14 minutes after their selection. These compare well with the corresponding average values calculated from the data in Table 2 (10:11 and 13:42, respectively). The additional time associated with DWR advisories involving weather are partially attributable to the extra time the AT Coordinator spent in deciding to Accept the DWR advisory, and possibly because of decision-making by the dispatcher and crew. A larger time interval might also occur because of coordination that the air traffic controller provided to allow the aircraft to fly the route correction.

Comparing the information in Fig. 15 to the rough estimate of four and a half minutes determined earlier as a best case for the Evaluation to Flight Plan Amendment process, the peak of 13 flight plan amendments at three minutes in Fig. 15 appears inconsistent with the rest of the data. These amendments may have been the result of controllers granting direct routes before the pilot requested it. In other words, these amendments may not be attributable to DWR advisories.

D. Change in Time-Saving Benefit

The potential time savings predicted for each DWR advisory changes as the aircraft continues on its original flight plan. The amount of change, usually a decrease, is a function of the winds and the geometry of the DWR route correction relative to the current route of flight. This section will present the change in flight time benefit for those flights that are believed to have received flight plan amendments based on a DWR recommendation.

The DWR software continuously updates the time savings for each advisory. To simplify this discussion, just the differences between two pairs of time saving values for each advisory are considered, each value linked to a specific event in the DWR timeline of Fig. 3. Figure 16 shows the change in potential time saving benefit from “Advisory” to “Acceptance”, plotted against the time that passed between these two events. A study on the first three months of the DWR operational evaluation called this “evaluation delay.”² In that report, reviewing 71 accepted advisories, most of the equivalent delays were comparable to those shown here, although in three instances the time from Advisory to Acceptance was in excess of 20 minutes. As in the other sections of this report, the advisories in Fig 15 have been separated into a set of Direct Route DWR and “All Other” DWRs, those affected by weather. As the time from Advisory to Acceptance is relatively short, most of these advisories saw a change in potential time savings of a minute or less, with very little difference in the zero to three minute time span. The losses show some increase as the time from Advisory to Acceptance increases, with Direct Route DWRs generally showing less scatter and less loss (about three minutes maximum) than the other advisories (about five minutes). Note that some of the points show a slight increase in time savings, either because the AT Coordinator modified the advisory to increase time savings, or because the progress of the aircraft gave the updated advisory a more beneficial path through the prevailing winds than the original advisory. The benefit losses were generally less than those reported previously², and might reflect better responsiveness of the AT Coordinator to alerts from the DWR system

Figure 17 shows the change in potential time savings from the Acceptance to Flight

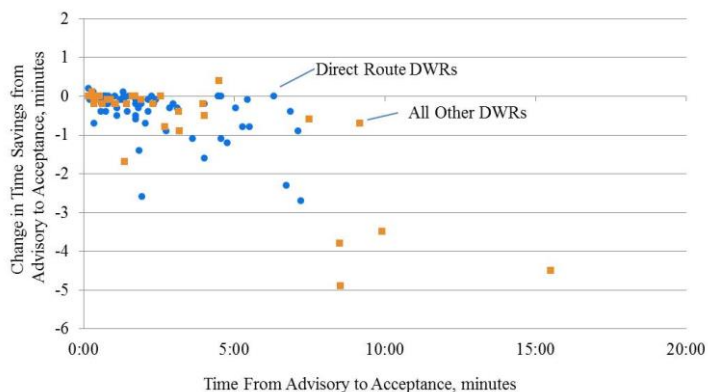


Figure 16. Benefit decay, from Advisory to Acceptance.

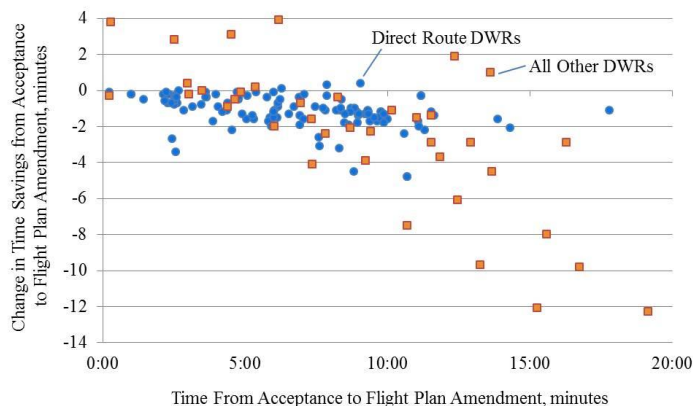


Figure 17. Benefit decay, from Acceptance to Flight Plan Amendment.

Plan Amendment. The study on the first three months of the DWR operational evaluation called this “execution delay.”² For 33 cases in that study, the data showed no clear trends, but the report noted examples of less than one minute lost with small execution delay, and two to three minutes of time savings lost with three to six minute execution delays. In this study, while the time span from Acceptance to Flight Plan Amendment is larger than that from Advisory to Acceptance for most cases, the data also show more scatter for data points with time spans equivalent to that in Fig. 16. For example, in Fig. 17 two Direct Route DWRs lost more than two minutes of flight time benefit in the three-minute time from Acceptance to Flight Plan Amendment; a large cluster of these points appear with one to two minutes of benefit loss in the eight to ten minute time range, with the highest Direct Route loss of about 5 minutes occurring when the flight plan was amended 12 minutes after Acceptance. The “All Other DWR” points show much greater variation in time elapsed between Acceptance and Flight Plan Amendment, as well as a wide variety of changes in benefit. The points with an increase in time savings indicate that the amendment resulted in a greater time savings than the Accepted advisory. The “All Other DWR” set has more instances of this, as well as cases that produced greater losses than the Direct Route set for the equivalent time between Acceptance and Flight Plan Amendment. Just as these route corrections can provide more per-flight benefit than Direct Route DWRs, the window for garnering these savings appears to be smaller. These case may represent fleeting opportunities, as aircraft gain and lose opportunities to maneuver around weather.

In general, the data reflect that the time saving benefits for the “All Other DWR” cases are more variable than those for Direct Route DWRs. The data indicate that more time benefit per advisory would be preserved by taking steps to speed the process from Acceptance through Flight Plan Amendment, versus the Advisory to Acceptance span. Improving the former could include more rapid communication from the DWR “system operator” (AT Coordinator or flight dispatcher), or making the DWR display visible to air traffic controllers and traffic managers.

E. Questionnaire Data

Action-dependent pop-up questionnaires provided the AT Coordinators a means to record the reasons why they took specific actions during the DWR operational evaluation. The questionnaires appeared in response to a total of 901 actions taken for DWR flights in 2013, of which 771 were Accepts, 2 were Accepts from a trial plan initiated from the flight data block, 21 were Accepts following a manual modification to a DWR-suggested flight plan amendment (for a total of 794 Accepts), and 107 were Rejected DWR advisories, as shown in Fig. 18. This equates to approximately an 88% overall acceptance rate and a 12% rejection rate. As noted previously, 42 of the “Accepts” were advisories selected more than once, hence the difference between the 794 “Accepts” noted in this section and the 752 “Accepts” in the previous sections. The study² of the first three months of the DWR operational evaluation reviewed questionnaire data from 71 “Accepts” and 18 “Rejections,” a slightly higher rejection rate of 20%. The AT Coordinators rarely initiated their own trial plan for the aircraft, letting DWR find savings instead of starting a trial plan from the flight data block on the PGUI.

For each Accepted advisory, two questions appeared in the questionnaire window. The first was, “How useful was the DWR system in finding a better route for this flight?” The options given were: No comment, Not useful, Moderately useful, and Very useful. 52% of responders rated the DWR system as highly useful for the just-accepted advisory, while another 25% rated it moderately useful, and 4% rated it not useful (Fig. 19). These ratings are a little less positive than those reported² following the first three months of the operational evaluation, which were 61% very useful, 23% moderately useful, and 0% not useful. This is not surprising given the longer evaluation time of this study, and a larger number of AT Coordinators that began using the display in this time period.

The second question asked for Accepted flights was, “How much confidence do you have that the route you selected will be issued?” The possible responses were No comment, Little confidence, Moderate confidence, and High confidence. 40% of responders had high confidence in the route being approved for the flight, while 30% reported moderate confidence, and 8% reported little confidence (Fig. 20).

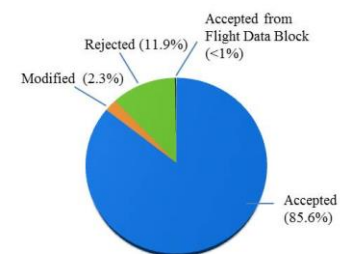


Figure 18. Actions that triggered questionnaires.

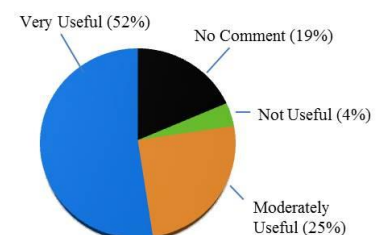


Figure 19. Usefulness of Accepted advisories.

While the AT Coordinators had moderate to high confidence of 70% of the 752 Accepted advisories becoming issued as flight plans, 28% (or, 211) of the Accepted advisories were made without any FACET data appearing on the DWR display. This occurred when the AT Coordinator inadvertently stopped the FACET process, or the data feed to FACET was not available due to system maintenance. Without FACET running, no information on sector congestion or potential conflicts with SAAs was available prior to Acceptance. Furthermore, 15 Accepts occurred for flights when the FACET data indicated a low likelihood of the flight plan

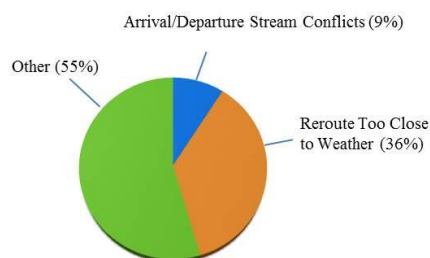


Figure 21. Reasons for modifying advisories.

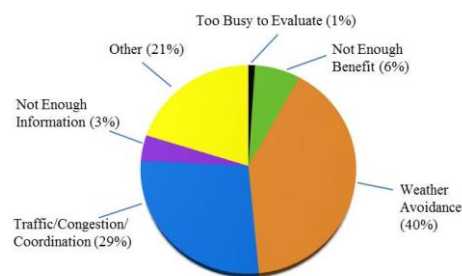


Figure 22. Reasons for rejecting advisories.

Arrival/departure stream conflicts came in at 9%.

DWR advisories were rejected approximately 12% of the time. At a top-level, the AT Coordinators gave the reasons shown in Fig. 22 for rejecting a route. Weather avoidance was quoted as a reason 40% of the time, while traffic, congestion, and/or coordination were given 27% of the time. "Other" was listed 20% of the time. The report² on the first three months of the operational evaluation had slightly different questionnaire choices, but it also showed weather (22%) and arrival stream, playbook, and sector congestion concerns (57%) as the primary reasons for rejection of a DWR advisory. Figures 21 and 22 compare well to each other, showing that the main concern with either modifying or rejecting a DWR advisory was the proximity of weather, followed by air traffic concerns. In fact, of all the DWR advisories that AT Coordinators rejected, 10 of the aircraft eventually received flight plan amendments from air traffic control that were similar to the DWR advisory, and a further 18 advisories could have been modified with the trial planner to avoid weather, but

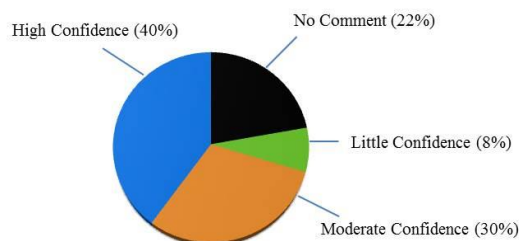


Figure 20. Confidence that Accepted advisory will become a Flight Plan Amendment

being amended, that is, the sectors through which the advised flight plan passed were congested, or the advisory passed through an active SAA. Lastly, four advisories were Accepted with either a FACET data error or stale flight plan data displayed on the screen.

Some of these inconsistencies in approving advisories, along with a high percentage of the "No Comment" answers on the survey, can be attributed to "routine" advisories that frequently appeared on the display and that the AT Coordinators frequently accepted, while others can be attributed to a busy AT Coordinator who acted on the DWR advisory but had other important tasks to complete. The questionnaire results generally reflect a positive confidence in the usefulness and practicality of DWR advisories, with the caveat that some of the decisions that the AT Coordinators made about the issuance of flight plan amendments may have been different, had they heeded FACET guidance to conduct a more careful review of the trial plan.

Asking these same two questions about the 21 advisories that AT Coordinators modified in the trial planner prior to Acceptance, the AT Coordinators responded that 62% of the advisories were very useful and that 38% were moderately useful. In 33% of the responses, users had high confidence in the route being issued, 24% had moderate confidence, and all others chose not to comment. The reasons given for modifying the proposed routes from that suggested by the DWR system are shown in Fig. 21. "Other" was most often selected (with no additional comments) for 55% of the responses, with "Reroute too close to weather" closely following at 36%.

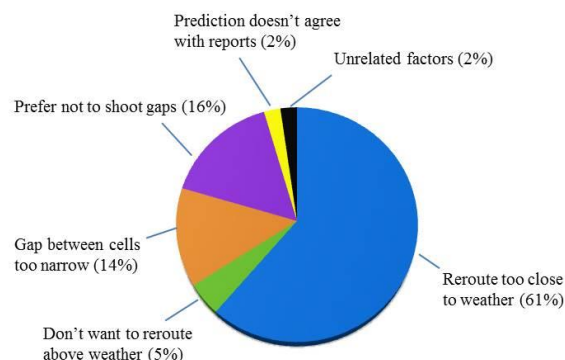


Figure 23. Reasons for rejections related to weather avoidance.

the AT Coordinator did not choose to do so. This suggests that some of the Rejections may have resulted in feasible, time-saving routes if the AT Coordinators had acted on them instead.

The questionnaires allowed the AT Coordinators to break down their reason for rejection into greater detail for two of the categories shown in Fig. 22: weather avoidance, and traffic, congestion, and/or coordination.

The top reasons given under weather avoidance include that the route was too close to the weather (61%), they would prefer not to shoot gaps (16%), and the gap between cells was too narrow (14%) (Fig. 23). The other three reasons together totaled 9%. In general, the AT Coordinators were more conservative about the space between aircraft routes and convective weather than the CWAM model projection of what the 70th percentile of pilots would avoid.

The top reasons given under traffic, congestion, and/or coordination were to avoid arrival/departure sectors (67%), the current sector was too busy (19%), and traffic conflicts (11%) (Fig. 24). These responses are consistent with video review of the rejected cases that showed that some rejected DWR advisories crossed arrival sectors, even though the aircraft was not predicted to actually enter into a conflict with specific aircraft. AT Coordinators generally had different “comfort levels” in these cases – some would reject these kinds of advisories, while others would accept them but concede that the recommended route modification was unlikely to be granted by air traffic control.

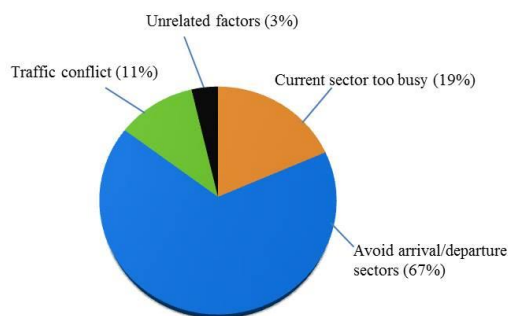


Figure 24. Reasons for rejections related to traffic, coordination, and/or congestion.

V. Conclusion

This analysis of the ongoing operational evaluation of the DWR system substantiates the conclusions of the previous work², categorizes the advisories to demonstrate the usefulness of the system in situations with and without convective weather, and indicates areas for system improvement.

While potential savings on a per-flight basis were greatest for suggested route corrections involving convective weather avoidance (averaging from 7.8 to 15 minutes per flight depending on the type of advisory), 40% of the potential savings from the year accrued from direct routes in clear-weather conditions (averaging 3.3 minutes per accepted advisory). American Airlines’ destinations and the departure route structure from D/FW Airport played a significant role in generating the opportunities for these clear-weather savings. Since most American Airlines flights in Fort Worth Center are either arriving or departing D/FW, over 90% of DWR advisory savings came from Air Traffic Coordinators acting on departures, and few from overflights. Results would differ for deployment of the DWR system for a different Center because of changes in demand, the patterns and direction of storms, and the geometry of the route structure.

Analysis of the process that AT Coordinators used in reviewing and requesting DWR advisories showed that the coordinators quickly decided to accept or reject route corrections, typically in one minute or less. A more significant time interval passed in sending route correction information to crews, in requesting flight plan changes from air traffic control, and in coordinating these changes within the air traffic control organization. Most frequently, the time from the selection of an advisory to an air traffic controller amending the flight plan was 10 minutes, for direct routes not involving weather. For route modifications involving weather, this process took longer, with 14 minutes as the most common time interval. Reducing this evaluation-to-amendment time can preserve potential time savings. The data indicate that approximately a minute of time savings could be preserved for a three to five minute reduction in the interval used for analysis, communication, and coordination. This is more critical for advisories involving convective weather because of the higher potential savings at stake, and because the time-savings benefit shows greater variability than in clear weather. In fact, not only did opportunities for routing aircraft behind convective weather (Backside DWRs) generally have higher potential savings per advisory, they took less time for the AT Coordinators to analyze and accept compared to DWR route corrections that passed closer to weather.

AT Controllers modified just 2.3% of the DWR system-proposed advisories that they accepted, and on average rejected one advisory for every seven that they accepted. Questionnaire responses showed that AT Coordinators found the DWR system useful, and had confidence that most of the suggested route modifications would be implemented by air traffic controllers. Proximity to weather, as well as air traffic congestion, coordination, and proximity to merging arrival streams were the primary reasons for DWR advisory rejection. Combining this information with the kinds of advisories accepted, the AT Controllers found the tool useful for saving flight time in all weather conditions, but prefer to be more conservative than the tool in routing aircraft close to weather.

Follow-up work should strive to tune the weather portion of the DWR system to more closely match the expectations of the AT Controllers and dispatchers. Full integration of the DWR system into the airline's operation center would be the key to reducing the time spent getting accepted advisories to the crew. Understanding when aircraft may cross sectors and altitudes usually dedicated to arrival and departure traffic flows would allow more efficient use of the system operators' time and priorities. Lastly, organizing candidate advisories by operating cost savings would also assist future users of the tool in finding the best candidates for direct routing.

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